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USE OF AQUEOUS SOLUTIONS OF WATER GLASS TO EXTINGUISH FIRES

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The use of an aqueous solution containing 5 – 10% water glass to extinguish fires is validated. As water evaporates from the solution on the combustion surface, water glass forms a viscoplastic insulating film, which under the action of high temperature foams and forms a porous insulting layer from the inorganic foam.

Key words: water glass, aqueous solution, fires, inorganic foam, insulating layer, density, viscosity, thermal conductivity.

Water is the most commonly used means for extinguishing fires. As water flows into the center of combustion and starts to evaporate, it absorbs a large quantity of heat and lowers the temperature of the combustion surface. Experience shows that water is quite effective; flare ups and low-temperature fires are negligible. In high-temperature fires the water stream may not reach the combustion surface and evaporate on arrival at the combustion zone. This is why large quantities of water are required to extinguish such fires.

The fire extinguishing liquid must not only lower the temperature at the combustion center by means of water evaporation or liberation of gases which do not support the combustion but it must also form on the combustion surface insulting films or other barriers which block oxygen inflow.

In addition, to reach the combustion surface the stream of fire-extinguishing substance must possess a higher critical energy than a water stream. This can be achieved by increasing the density of the liquid by introducing substances into it that increase not only the density but also the viscosity of the water. As a rule, additions of inorganic salts — alkali-metal chlorides, carbonates, and bicarbonates as well as additions of clay and other finely dispersed substances — are used as thickening agents.

The best inorganic thickening agent of the many such substances available is water-soluble sodium silicate (water glass) with density 1380 – 1500 kg/m^3 and dynamic viscosity to 1 Pa · sec [1]. Water glass mixes with water in any ratio; for water glass content from 5 to 50% in an aqueous solution the water glass changes the solution viscosity from 0.004 to 0.5 Pa · sec and increases the solution density from 1020 to 1250 kg/m^3.

In the indicated range of water glass content in an aqueous solution, the viscosity of the solution increases by a factor of 4 – 500 as compared with that of water (0.001 Pa · sec, 20 °C).

Increasing the solution density will make it possible to increase the flight distance of the stream by increasing its kinetic energy.

As the water-glass solution streams moves to the combustion surface, the solution is heated because of the high temperature and the viscosity of the solution decreases, which improves the adhesion of the solution to the combustion surface. To increase the wettability and spreading of the solution on the combustion surface, 0.001 – 0.1 kg/m^3 water surfactants, whose surface tension is of the order of 30 mN/m, can be added to the solution.

As water evaporates from the solution, the concentration of water glass on the combustion surface and the viscosity of the solution increase. When the water has completely evaporated from the solution, a continuous water-glass film remains on the combustion surface. At temperatures 120 – 200°C this film loses molecular water and becomes solid-like (a xerogel).

In the temperature range 200 – 400°C the chemically bound water, which makes the water-glass film pyroplastic, while the water vapors displace this skin because of the sharp increase of their volume and the skin volume increases 10 – 50-fold, is removed from the xerogel. The density of the foam formed on the combustion surface of the layer is 30 – 50 kg/m^3, and this layer reliably blocks the oxygen in the air from reaching the combustion surface. The foam layer formed is not subject to combustion, since it is an inorganic substance — a water-free alkali-metal silicate.

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TABLE 1. Test Results on the Effect of the Silicate Modulus of Water Glass on the Foaming of the Glass

Water glass modulus	Foaming ratio	Tests results
1.0	–	Glass layer partially fused, smoking
1.5	3.5 – 4	Partially porous layer fused with the surface, smoking
2.0	5 – 8	Small foam layer, weak smoking
2.5	15 – 18	Dense foam layer, no smoking
3.0	40 – 50	Porous foam layer
3.2	40 – 50	Porous foam layer
3.4	40 – 45	Porous foam layer

In addition, the solid inorganic foam layer formed has a low thermal conductivity 0.03 – 0.036 W/(m · K) and prevents the extinguished surface from being heated to the combustion temperature because the heat flux formed by the flame and the convective heat from the exhaust gases becomes considerably weaker. The foam retains its structure and properties to temperature 550°C, above which partial melting of the surface of the foam layer and densification of the layer start. In addition, a definite amount of heat is expended on melting the surface layer of the foam.

Water glass with silicate modulus 2.5 – 3.2 must be used to prepare fire extinguishing solutions, since the foaming intensity of water glass under thermal heating depends on its content of molecular, chemically bound water, whose amount in the water glass is predetermined by its modulus and the structural nature of the silicate anion [2, 3].

Depending on the modulus the following predominate in water glass: the polymer anion $[SiO_3]^{2-}$ for $m = 1$; the ribbon polymer anion $[Si_2O_5]^{2-}$ for $m = 2$; and, the polymer anion with repeating radical $[Si_3O_7]^{2-}$, forming a three-dimensional structure, for $m = 3$ or higher. The higher the modulus, the higher the content of molecular water in the water glass is and the greater the foaming capability of the latter is.

The effect of the magnitude of the silicate modulus of water glass on its foaming process was checked by depositing on the surface 1 × 2 cm wooden racks of water glass with silicate modulus $m = 1 – 3.4$. Next, the racks with the water glass were dried in a desiccator (80°C) for 20 min, after which they were placed in a muffle furnace preheated to 600°C and held in the furnace for 1 min. The foaming ratio of the water glass was determined according to the ratio of the thickness of the foam layer to the thickness of the initial film of water glass. It should be noted that no charring of the wooden racks was observed beneath the foam layer. The results of the tests are presented in Table 1, whence it follows that water glass with modulus above 2.5 has good foaming capability.

The use of an aqueous solution of water glass as a means of extinguishing fire is of fundamental importance. This is because water entering the combustion center rapidly evaporates and physical–chemical processes forming from the water glass a pyroplastic insulating film develop. Subsequent heating engenders a physical–chemical process that forms a layer of inorganic insulating foam which is stable to 550°C and prevents the oxygen in air from reaching the combustion surface.

If the water glass in the fire-extinguishing solution acts as a thickening agent, then the water in the solution acts as a medium transporting water glass to the combustion center.

Simple calculations showed that up to 1.5 m^3 of inorganic foam are formed when 1 m^3 of a solution with 10% water glass reaches the combustion center. If the solution contains 50% water glass, then the foam volume formed from 1 m^3 of solution will be 5 – 10 m^3 with foam density 30 – 50 kg/m^3.

These calculations suggest that when aqueous solutions of water glass are used to extinguish fires, the consumption of this extinguishing agent can be reduced 5 – 10-fold as compared with water. The following factors can be used to evaluate the predicted effectiveness of aqueous solutions of water glass for fire extinguishment:

– the water glass easily dissolves and mixes with water in any ratio;

– highly concentrated solutions are best used for extinguishing oil spills, oil and gas well fires, underground fires in coal mines, and ignition of peat bogs;

– a solution can also be used for fire prevention by preventing the ignition of other objects located near the focus of a fire, for example, the walls of wooden buildings and individual trees and brushwood in the case of forest fires;

– fire engines can deliver the fire extinguishing solution to a burning object; in the case of forest fires it is recommended that the solution be added to the fire extinguishing media carried in backpacks;

– the solution is very effective for extinguishing high-temperature fires;

– the solution is safe for people and the environment (but an effect on soil pH has not been ruled out);

– the cost of water glass is not even comparable to the economic losses due to fires.

In conclusion, it should be noted that water glass is a typical nanodisperse system, possessing a unique ability to form solid inorganic foam when thermally heated. This property predetermines a new field of application of water glass for extinguishing fires of any complexity.

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